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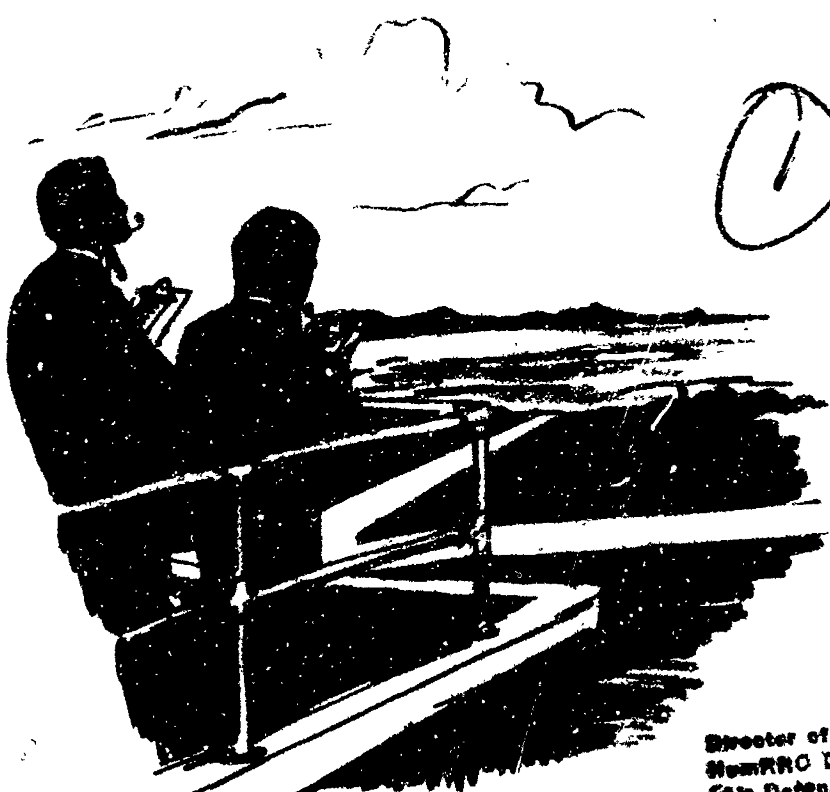

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TECHNICAL REPORT NO. 4

FIELD STUDY OF THRESHOLD RANGES FOR AIRCRAFT DETECTION AND COLOR IDENTIFICATION

Prepared by
APPLIED PSYCHOLOGY CORPORATION
for
FEDERAL AVIATION AGENCY

TECHNICAL REPORT NO. 4

FIELD STUDY OF THRESHOLD RANGES FOR AIRCRAFT DETECTION AND COLOR IDENTIFICATION

Prepared by

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For

Federal Aviation Agency
Washington 25, D. C.

This report has been prepared by the Applied Psychology Corporation for the Aviation Research and Development Service (formerly Bureau of Research and Development), Federal Aviation Agency, under Contract No. FAA/BRD-127. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the ARDS or the FAA.

June 1961

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ACKNOWLEDGEMENTS

The investigators wish to acknowledge their indebtedness to the many persons whose cooperation and contributions made this study possible, and in particular, the original contract monitor, Dr. H. Richard van Saun; the current contract monitor, Eugene E. Pazera; and George Ashley, Chief, Washington Tower, and his staff.

SUMMARY OF THE PROJECT

More than 85% of all mid-air collisions have occurred during VFR operations. Since in all likelihood a substantial majority of flights will continue to take place under Visual Flight Rules for some years to come, the Federal Aviation Agency in July 1959 established a program calling for comprehensive research into visual aids for preventing mid-air collisions.

The principal areas being investigated by the contractor, the Applied Psychology Corporation, are paints, exterior light systems, smoke and vapor trails, optical devices, training procedures, and a determination of those items of information needed by pilots for making ~~reliable~~ avoidance-maneuver decisions.

The approach ~~consists of~~ a progression from laboratory work, through field tests, to flight testing. Experimental studies have been conducted to derive those quantitative data regarded as prerequisite to efficient and practical field tests. The field tests have then been designed to assess promising devices and techniques through ground-based observations; as such, they served as economical screenings prior to flight tests.

In-flight evaluations have been reserved for final testing of proposed solutions and for investigating operational problems.

Technical Reports have been, and will be, issued as statements of particular experiments or analytical studies; *Summary Reports* will be issued as summarizations of all work done in the various broad areas of investigation (e.g., paints, exterior light systems).

The present report is Technical Report No. 4. Other reports, both published and planned for publication, are listed below:

Technical Reports

No. 1	Analysis of the Usefulness of Coded Information in Visual Collision Avoidance
No. 2	Comparative Conspicuity of Several Aircraft Exterior Paint Patterns
No. 3	Aircraft Flight-Attitude Information as Indicated by Exterior Paint Patterns
No. 5	Pilot Judgments of Simulated Collisions and Near Misses: A Comparison of Performance with Uncoded and Two-Tone Coded Models
No. 6	Effects of Backscatter on Perception of Target Lights A. Foveal Observation of Steady-Burning Lights
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No. 8	Flight Simulator Tests of Altitude-Coded Lights
No. 9	Effects of Backscatter on Perception of Target Lights B. Peripheral Observation of Flashing Lights
No. 10	Pilot Judgments of Aircraft Range and Relative Altitude A. Ground-to-Air Observations

Summary Reports

Abstract

Over 500 operational aircraft were observed, in order to obtain a rough approximation of the range at which aircraft become visible and at which color on them can be identified. Data were collected so as to permit exhaustive examination of all the factors which might influence these ranges.

Paints were found to have no effect on aircraft threshold ranges. There were found to be slight relationships with the following elements of the observation situation: cloud backgrounds, sun elevation, ground visibility, brightness contrast, and individual differences among observers. Relative ranges for various sun, aircraft, and observer positions were found to follow closely the rankings predicted by earlier investigators working with a theoretical model. Aircraft size and aspect were related to threshold range, but not as precisely as predicted.

Within the somewhat limited range wherein colors can be identified, fluorescent colors were identified more than twice as far as non-fluorescent colors.

TECHNICAL REPORT NO. 4

FIELD STUDY OF THRESHOLD RANGES FOR

AIRCRAFT DETECTION AND COLOR IDENTIFICATION

The ranges at which aircraft of various sizes can be detected has been the subject of much discussion and apparently very little empirical research. Air-to-air distance estimations, without a check on their accuracy, can be misleading. In addition, there are a number of variables which can affect the range at which other aircraft are visible. When aircraft detection ranges have been quoted in the literature, all of these conditions have usually not been specified. Also, the observations have sometimes been made under a quite limited range of these conditions; this is understandable, since many of the pertinent conditions are natural phenomena not subject to experimental manipulation. Further, (the cost of using aircraft and distance measuring equipment, such as radar, is quite high)

Several factors motivated this field study of threshold ranges for aircraft. Among these factors are the following:

(a) Time and cost factors severely limit the number of observations that can be obtained with carefully controlled

air-to-air and ground-to-air observations, even though such carefully controlled experimentation is always the ultimate research goal.

(b) Time and cost factors limit the number of different types and sizes of aircraft which can be used in any controlled experimentation. There is also the very real practical problem of obtaining a variety of aircraft types for experimentation.

(c) It was felt the results of objective field observations would supplement the findings of certain air-to-air and ground-to-air experimental studies planned as part of this broad visual-collision-avoidance research program.

(d) The facilities of the Washington National Airport were readily available for a field study. This airport provided a wide variety of types of civil and government aircraft, a high traffic volume enabling reasonable data collection time, and radar facilities to measure aircraft ranges.

Method and Procedures

Observers. Six persons served as observers. All had visual acuity of at least 20/20 with correction. Two had pilot experience, another was a member of the Air Force ROTC program, and all were members of the research staff on the visual-collision-avoidance program.

Physical arrangements. Two aircraft observers were stationed on a porch immediately below the Washington National Airport control tower; a radar monitor was positioned at a horizontal video representation of the radarscope in the Washington Approach Control operations room, two floors below. The two observers and the radar monitor were continuously in voice contact with each other through a battery-operated closed-circuit telephone system. Each observer and the radar monitor had an individual headset-mike combination instrument and a small junction box. The junction boxes were interconnected by single wire extension cords so as to permit the two aircraft observers to move freely about their porch. Without need for call-up or button pressing, the observers' hands were free for recording data. Figures 1 and 2 illustrate the observers' position and equipment.

Data recording. Separate recording forms were provided for approaching and for departing aircraft. For approaching aircraft, initial contrast, range, and bearing were recorded first, while for departing aircraft, the airline (if applicable), aircraft type, and a description of the color pattern were recorded first. These forms appear as Fig. 3.

Originally it had been intended that arriving and departing aircraft would be paired, not only by type of aircraft and paint pattern design, but also according to

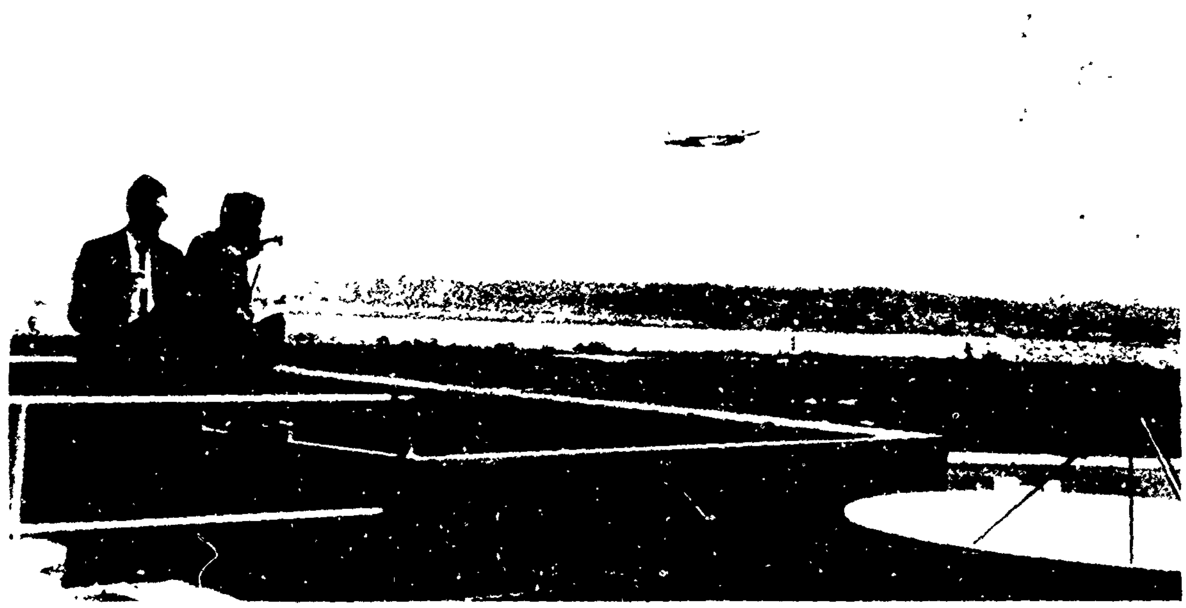

Fig. 1. Observers in position.

Fig. 2. Observer with recording and communication equipment.

DAYLIGHT OBSERVER RECORD
AIRPORT TOWER
APPROACH

Contrast: P___ N___ B___ S___

Range ______________

Bearing ______________

O'clock ______________

Color:

	Color	Location
Range		
Bearing		
Heading		
O'clock		

	empennage	fuselage	wings
Pattern			

Airline ______________

A/C Type ______________

Sun azimuth ______________

Time: EST_____ GMT_____

Date ______________

Observer ________ Radar Opr.______

Unusual atmosphere ______________

Ceiling ______________

Ground visibility ______________

Cloud Cover ______________

Transmissometer ______________

Sun Elevation ______________

DAYLIGHT OBSERVER RECORD
AIRPORT TOWER
DEPARTURE

Sun azimuth ______________

Airline ______________

A/C Type ______________

Color:

	empennage	fuselage	wings
Pattern			

	Color	Location
Range		
Bearing		
O'clock		

Contrast: P___ N___ B___ S___

Range ______________

Bearing ______________

O'clock ______________

Time: EST_____ GMT _____

Date ______________

Observer ________ Radar Opr. ______

Unusual atmosphere ______________

Ceiling ______________

Ground visibility ______________

Cloud Cover ______________

Transmissometer ______________

Sun Elevation ______________

Fig. 3. Replica of data collection forms used.

directions of approach and departure, sunlighting effects, and types of cloud cover, if any. Accordingly, to assist the observers in picking appropriate departing aircraft to match tabulated arrivals, comprehensive schedule sheets were prepared, showing airlines, types of aircraft, departure times, and destinations. As it turned out, however, departing aircraft proceeded to assigned fixes and often disappeared before finally turning toward their destinations, while prevailing winds during the period of observation usually resulted in approaches being made from another common direction bearing little relation to the aircraft's point of departure.

A listing of the data intended to be recorded on the "Daylight Observer Record" forms (Fig. 3), together with a discussion of the scope and source of each bit of information, follows:

(a) Contrast. Spaces were provided for P (positive), N (negative), B (both positive and negative, such as a white or sunlit fuselage top, with dark gray appearance of the bottom of the wings and fuselage), and S (specular, or the glint of sunshine on a polished surface). For arrivals, this entry was made first; for departures, at last sighting.

(b) Range, in nautical miles, and Bearing, in degrees clockwise from true north, were provided to the aircraft observers by the radar monitor. As a general rule, for arrivals, the radar monitor would direct an observer's attention toward a particular direction several minutes before the aircraft became visible to the observer; the observer would then announce the sighting, and the radar monitor would give the range and bearing. On departures, the observer periodically checked the range and bearing of the aircraft he was watching, so as to be sure the radar monitor could give him data for the correct aircraft at the moment it faded from view.

(c) Aspect observed. For both arrivals and departures the radar monitor announced the approximate clockwise view of the aircraft, as it was either first detected or finally lost sight of, using "o'clock" designations for viewing angles, with 12 o'clock being at the aircraft's nose.

(d) Color identification and Paint Pattern. When color could first be identified on an approaching aircraft, the observer so announced. The radar monitor read off the range, bearing, and observed aspect (o'clock). The color, and its location on the aircraft when first identified, were recorded. Whenever color was identified or lost at too close a range for radarscope determination of range and bearing (as often happened), the observer made estimates based on certain airport area landmarks. After the landing

at Washington National Airport, or as the aircraft passed nearby on its way to land at Bolling AFB or Anacostia Naval Air Station, across the Potomac River, the observer recorded the color pattern on the empennage, fuselage, and wings. For departing aircraft, the color pattern, and data as to range and bearing when color could last be seen, were similarly recorded. White, black, and gray were not considered to be colors, for color-identification purposes, since all surface colors become increasingly gray, due to atmospheric attenuation, as their distance from an observer increases.

(e) Airline and Type of Aircraft. These were recorded before takeoff or after landing. Aircraft of U. S. Government services or agencies, and private aircraft, were recorded as such.

(f) Elevation and Azimuth of the Sun. Elevation of the sun, when shining, was periodically obtained with a simple pin-shadow device. The sun's azimuth was taken from a mean solar azimuth table constructed for the mean solar time at each twenty-minut [illegible]erval of Eastern Standard Time.

(g) Weather data [illegible] obtained and entered from official airport weather observer's records maintained by the U. S. Weather Bureau office near the tower. These data included ceiling, ground visibility, and type of cloud cover. Entry spaces for transmissometer readings were also provided on the forms, but were not used because of the

limited spread of readings they provided for the viewing distances at which observations were to be taken.

(h) Date, Time (EST), and Observers' Initials were also entered. The time of day indicated was that moment the aircraft was detected or lost.

Results and Conclusions

A total of 541 ground-to-air observations was recorded between January and late April 1961. Collection of weather records for each observation took place during the same period. All data were punched on machine record cards. Computations consisted of determining the means and standard deviations of a number of different tabulations.

General Precautions in Data Interpretation

In any consideration of the analyses of the threshold ranges and color-identification ranges recorded during the series of Washington National Airport observations, the reader must bear in mind a number of technical considerations that may affect the universality of any stated conclusion.

(a) Observations of aircraft in flight were made from a fixed position on the ground, and slantwise through the atmosphere at the earth's surface, rather than from a moving flight position and through the atmosphere at flight altitudes.

(b) Observers of arriving aircraft could give their

entire attention to detecting one particular aircraft in a known direction, rather than to a search for <u>any</u> aircraft (possibly non-existent) in any direction. Likewise, the observations of departing aircraft received undivided attention until the aircraft "speck in the distance" was no longer discernable. In any air-to-air observations a pilot's attention would nearly always be divided between cockpit and airspace and would therefore result in lower ranges than those possible under these conditions.

(c) Certain colors and color patterns (particularly fluorescents) that from the outset were intended to add to the conspicuity of an aircraft are directly compared with other colors and color patterns that in many cases are intended only to be pleasing displays of an airline's corporate colors or of a private pilot's fancy. Because a particular color may be quite popular in its usage does not necessarily indicate that all who use it consider it to be more conspicuous.

(d) Many of the variables could not be controlled, and some could be measured only by rough approximation. Brightness contrast, for example, was measured only by observer classification of the contrast as one of four categories.

Effects of Paints and Paint Patterns on Detection

All detection (or "lost") ranges reported in this section refer to threshold ranges. At these ranges, <u>size</u>

of the image is probably the most important factor. Certainly, recognizing paint color or pattern as such is beyond any possibility. However, in order not to miss any variable which might have a bearing on threshold ranges, these factors were analyzed.

Figure 4 presents the average threshold range as a function of the predominant color on the aircraft. This figure illustrates some of the pitfalls possible when only one variable is inspected at a time. The averages for maroon and for yellow paints are considerably below those for other paints. However, the total number of these aircraft was very small, and they were mostly medium and small aircraft, while the other colors were mostly on large aircraft. The same caution must be used in interpreting the very slight difference between the average range for fluorescent paints as opposed to some of the non-fluorescent colors. Almost none of the fluorescent aircraft were of large size.

Figure 5 illustrates graphically the minor differences between fluorescent and non-fluorescent painted aircraft, when the effects of aircraft size are held constant. The differences between over-all average threshold ranges for the two types of paint, for all three sizes of aircraft, can be explained by chance variations.

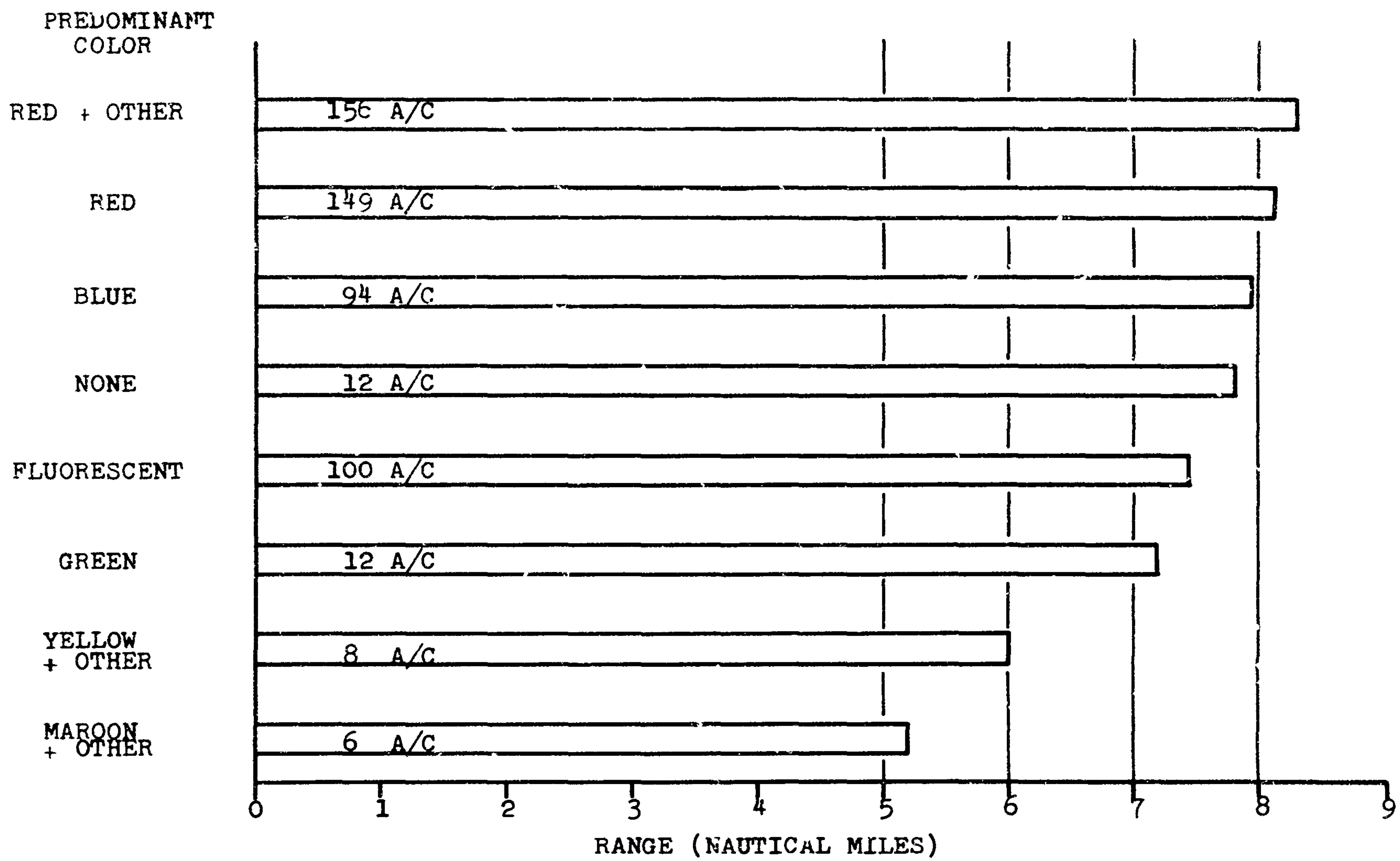

Fig. 4. Average threshold range of aircraft as a function of the predominant color on the aircraft.

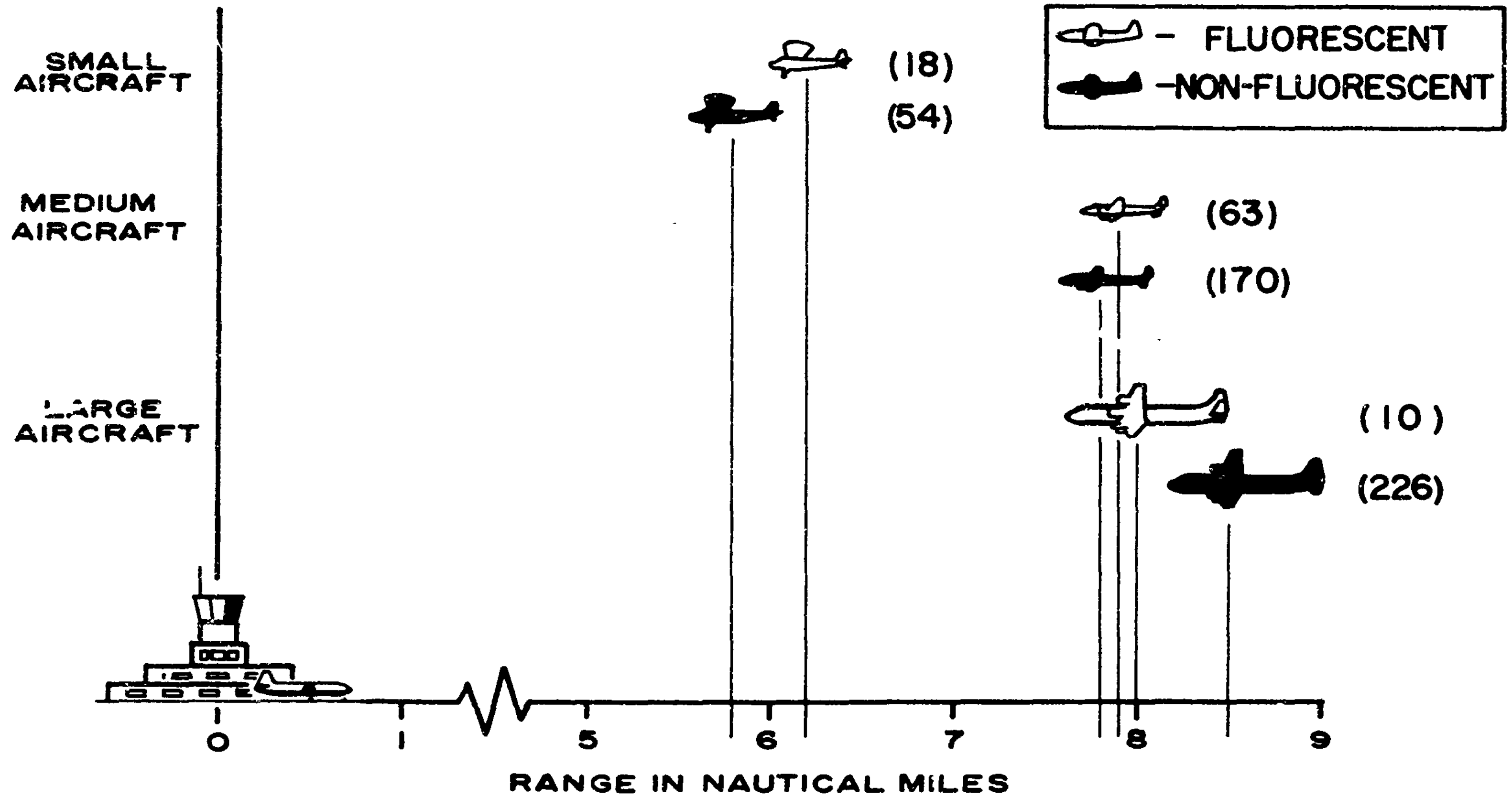

Fig. 5. Average threshold ranges for fluorescent painted and non-fluorescent painted aircraft as a function of aircraft size.

From aircraft bearings and sun azimuths recorded during the observations, it was possible to determine in each case the angle of the sun, the aircraft, and the observer--which is the angle between the line-of-sight bearing of the aircraft from the observer, and the direction of the sun's rays toward the aircraft. These angles fall between 0° and 180°. An angle of 0° means that the observed aircraft is on the opposite side of the observer from the sun (observer's back is to the sun); an angle of 180° means the aircraft is seen directly into the sun, except for elevation; and an angle of 90° means that the aircraft is seen directly to the right or the left of the observer as he either faces, or has his back to, the sun.

It was expected that the best negative contrasts would be obtained when the sun was behind the aircraft; and that some light would be reflected, and negative contrasts would be lessened when the sun was behind the observer. Hence, there might be a considerable difference in range, as the position of the sun relative to the aircraft changed, and the higher-reflectance fluorescent paints would influence this difference.

Figure 6 shows the variations obtained as sun position relative to the line of sight changed. While there may appear to be some differences in threshold range between fluorescent and non-fluorescent painted aircraft, it should

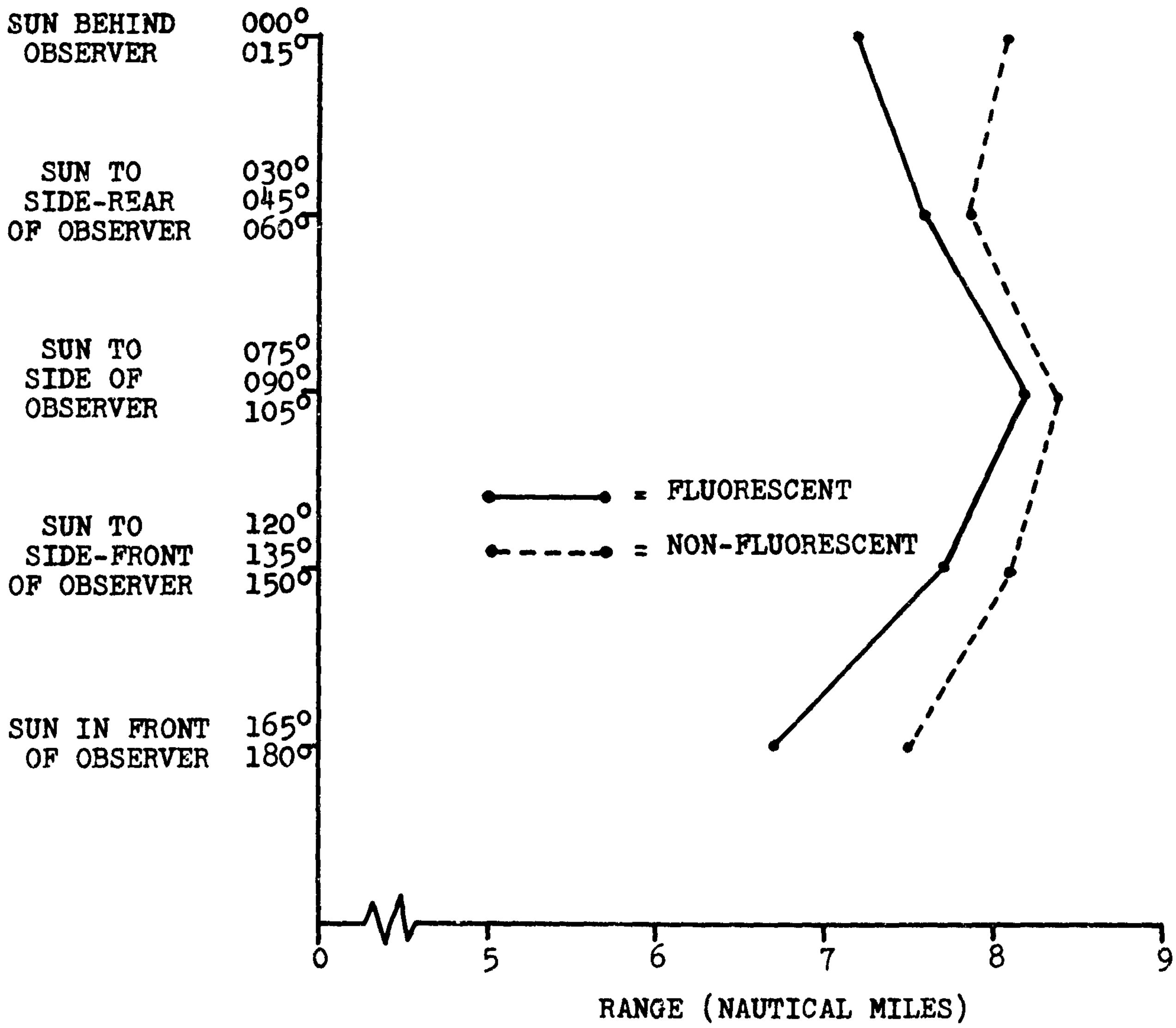

Fig. 6. Average threshold detection ranges as a function of sun position relative to observer's line of sight.

be mentioned once again that the observations include very few fluorescent painted large aircraft. Any differences between types of paint which might be evident from these data may very well be caused by differences in size alone. There do appear to be some slight differences in threshold range as a function of the angle of the sun, the aircraft, and the observer. Observing both into the sun and with one's back to the sun are detrimental to maximum threshold range. "Sidelighting" (sun at 90° to the line of sight) seems to produce the best threshold ranges.

During the period of the observations, several observers commented that under particular atmospheric conditions, the white tops of the fuselage of many of the aircraft were very easy to see and made tracking of the aircraft somewhat easier than when there was no white top. These data were recorded to check whether the color of the top of the fuselage was in fact an aid to threshold range. The average threshold ranges appear in Figure 7. Differences are not great (less than a mile), and again probably reflect chance variations.

Since the observers noted the advantage when there was a light atmospheric haze, the average threshold ranges were computed for aircraft observed when reported ground visibilities were 8 and 10 miles. Figure 8 presents the results of this analysis. The sample sizes are small but certainly do not indicate any advantage of a white top for threshold ranges.

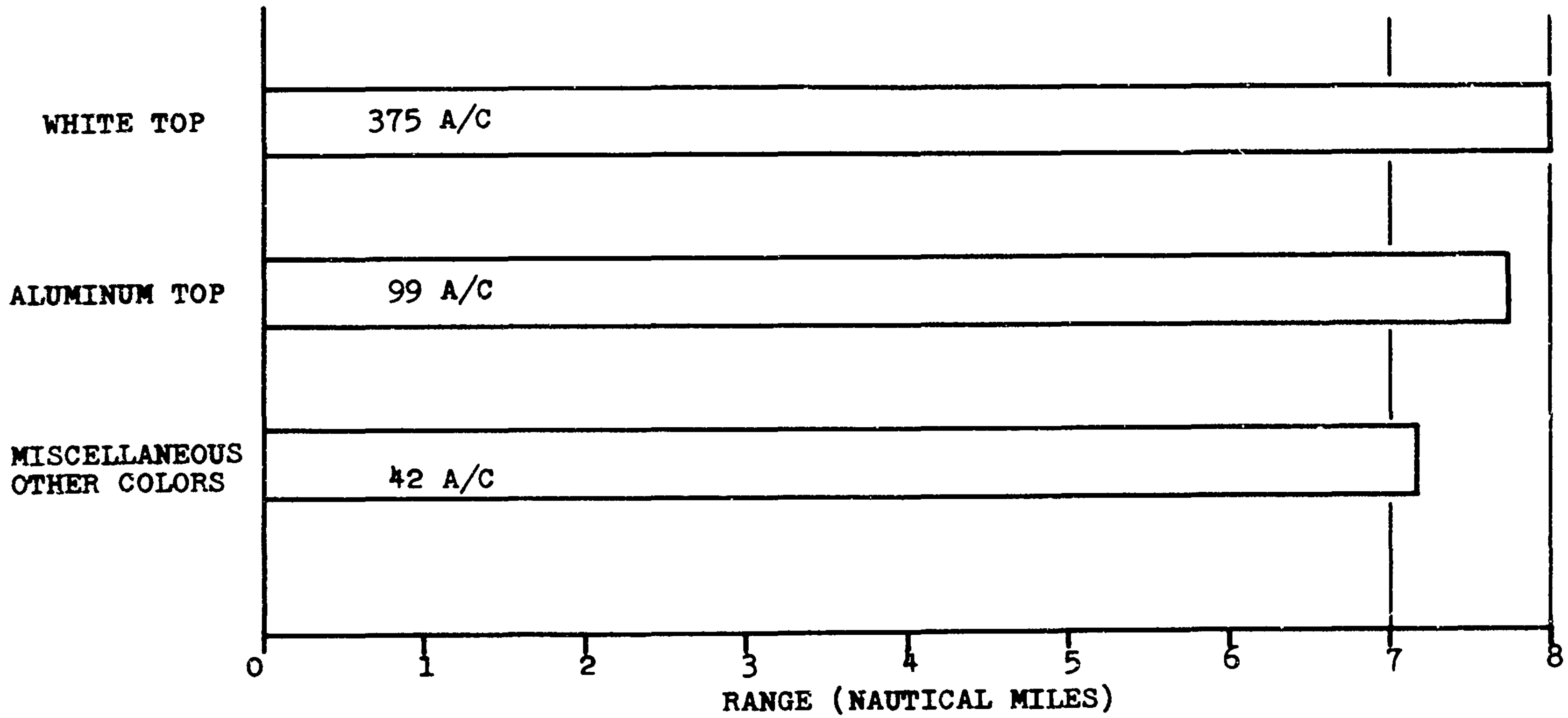

Fig. 7. Average threshold range of aircraft as a function of the color of the top of the fuselage.

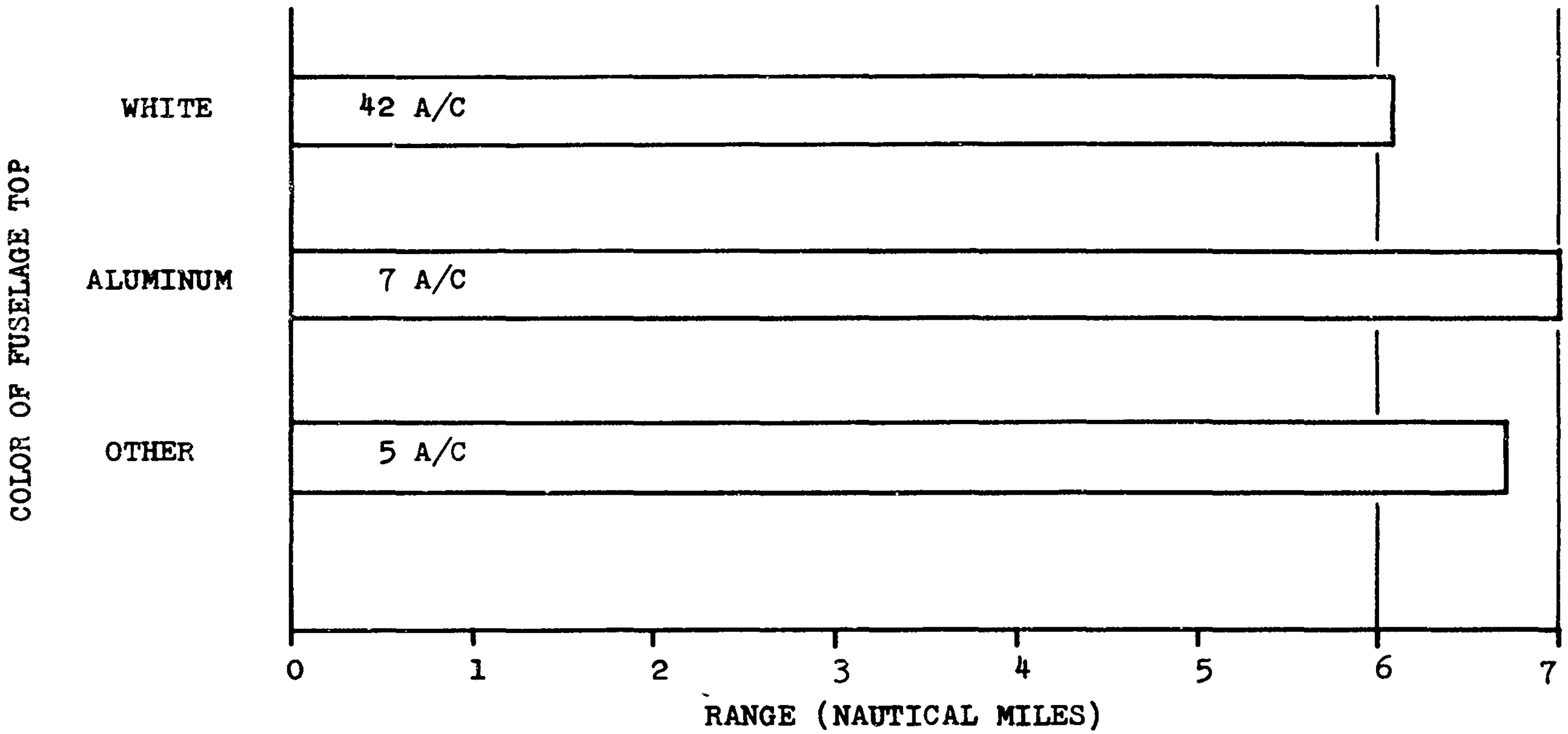

Fig. 8. Average threshold ranges as a function of color of top of fuselage when reported ground visibility was 8 and 10 miles.

Environmental Effects

There are a number of natural variables such as ground visibility, cloud covers, sun elevation, and time of day, which might affect aircraft detection range; for purposes of this report, these are called environmental effects. There are other variables such as brightness contrast and individual differences of observers, which are not necessarily natural phenomena but which might also affect detection ranges; these are called situational effects in this report.

Records of ground visibility were obtained from the Weather Bureau to serve as gross measures of atmospheric transmissivity. The great majority of observations was made when ground visibility was 15 miles or more. A brief inspection of Figure 9 reveals that ground visibility has some relationship to the range at which aircraft may be visually detected or lost, even though this relationship is far from perfect. (Ground visibility is usually reported in statute miles, but has been converted to nautical miles in Fig. 9. This is the reason for the maximum of 13, 13+ miles instead of the 15 miles mentioned above.) Ground visibility ranges are gross estimates at best, and, of course, refer to visibility of large objects (buildings, hills, etc.) viewed along the surface at a particular point in time.

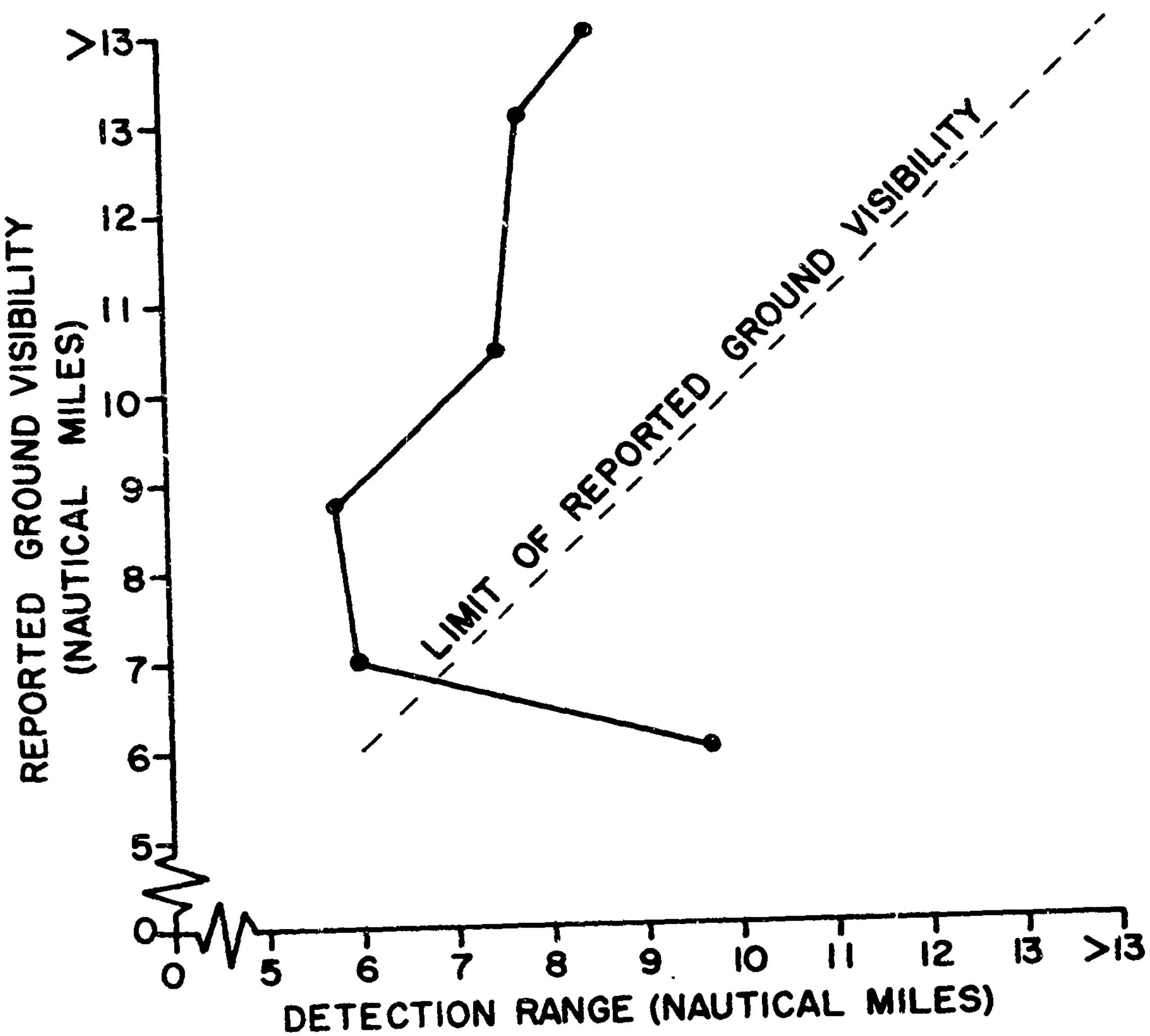

Fig. 9. Average threshold range as a function of ground visibility.

Visibility ranges somewhat above the surface may be greater than the visibility at the surface from moment to moment. When this happens, aircraft may be detected considerably farther than the reported visibility. The outstanding instances in these observations were four large aircraft seen at an average distance of 11.25 miles, when the reported visibility was only 7 miles.

While it is possible to see aircraft at greater ranges than the reported visibility, the more usual case is to detect aircraft at considerably <u>less</u> than the reported visibility. With visibilities between 8 and 10 miles, aircraft in this study were detected on the average at about 5- 3/4 miles. Even with visibility over 15 miles, aircraft were detected (or lost) at an average distance of 8-1/2 miles. None of the 541 aircraft observed in this study was seen at a distance greater than 15 miles under any condition.

Weather conditions are complex situations to attempt to categorize for purposes of data analysis. Except for perfectly clear conditions, any categorization loses something of the actual situation. However, two attempts were made to classify cloud conditions into reasonable categories for analysis.

Figure 10 presents the relationship between threshold range and the altitude of the highest cloud cover. This

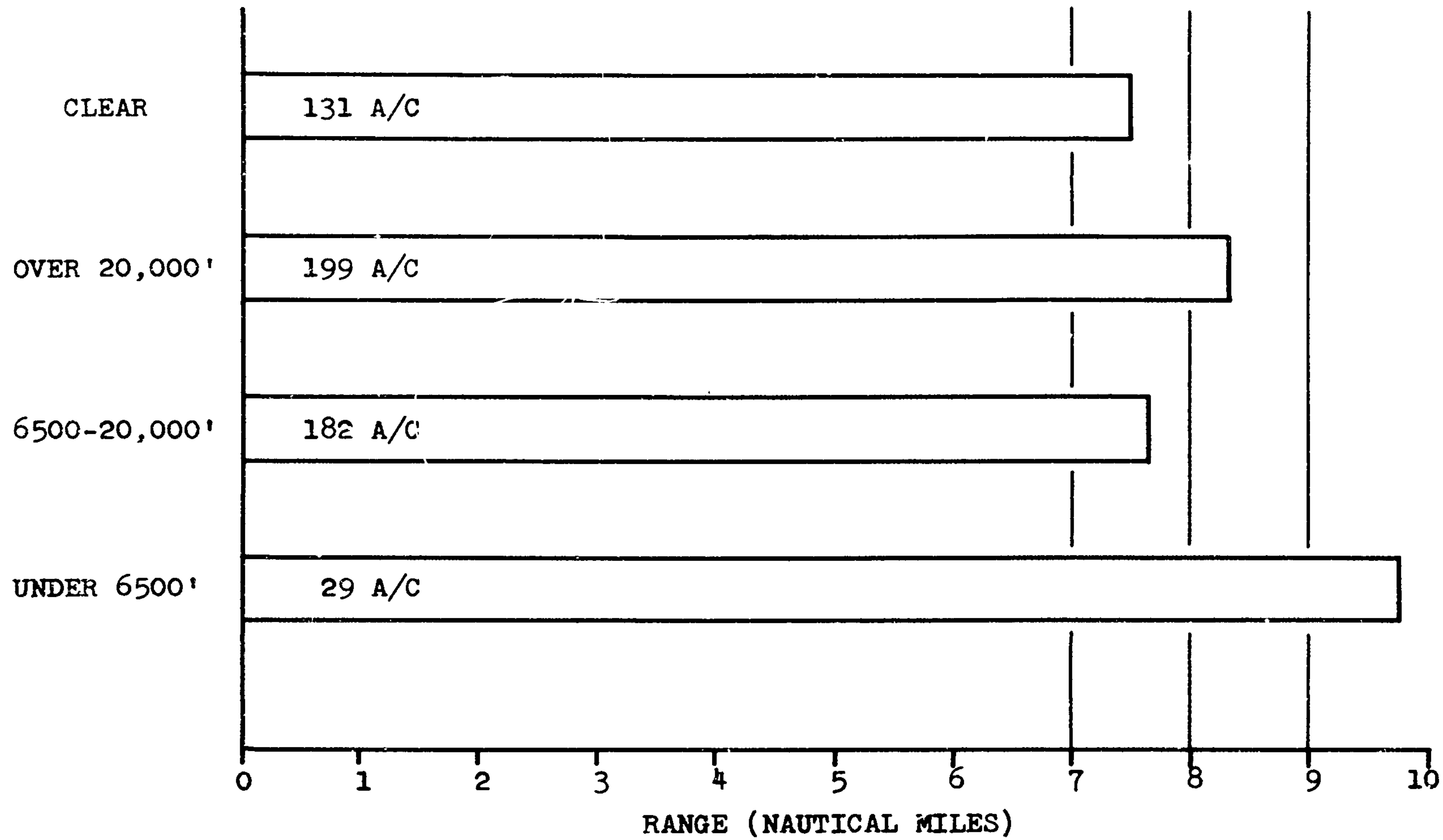

Fig. 10. Average threshold range as a function of cloud altitude.

analysis gives no information about the extent of the coverage. Some inferences can be made of the general type of cloud occurring at the three altitude categories commonly used by meteorologists. There seems to be no correlation between threshold range and cloud altitude.

Threshold ranges were greater for all conditions in which there were clouds. Possibly this indicates that a white-cloud background provides greater negative contrast than clear blue sky, and this may increase threshold range. To examine this possibility, Fig. 11 combines the effects of cloud altitude and cloud coverage. If the interpretation were correct, then threshold range would be greater as the cloud cover increased. Figure 11 indicates that such is not the case.

Ogilvie and Baker (1954) in an analytical study of factors affecting aircraft visibility, mention elevation of sun above the horizon as one important variable. Its importance stems from the amount of illumination available when the sun is at various distances above the horizon. Illumination is fairly constant above 30°; there is no change in the theoretically possible visual ranges above this level.

Average threshold ranges for various sun elevations are presented in Fig. 12. Although the differences between visual ranges are small, there does seem to be some trend in favor of slightly greater visual ranges as sun elevation becomes less.

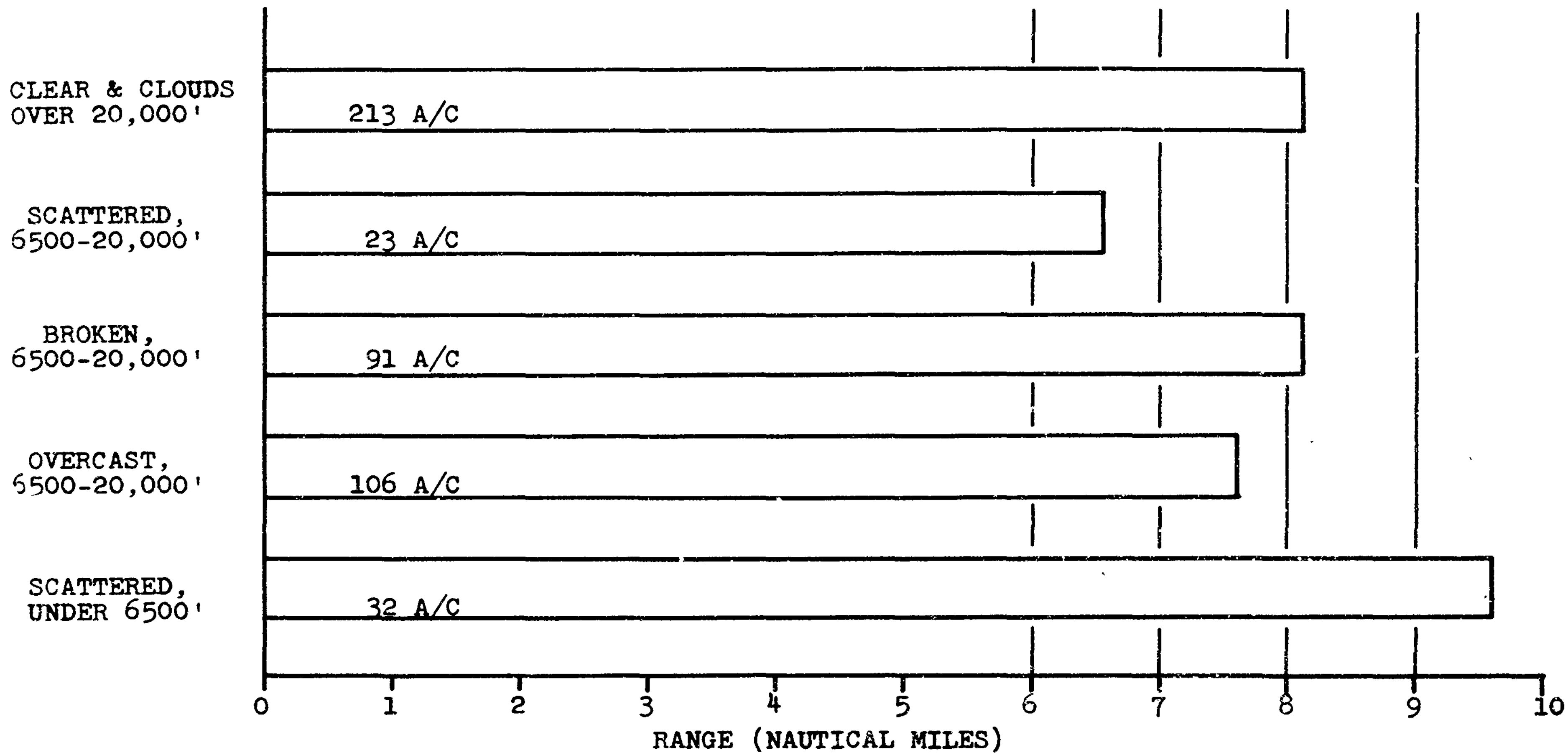

Fig. 11. Average threshold range for aircraft as a function of the lowest predominant cloud cover.

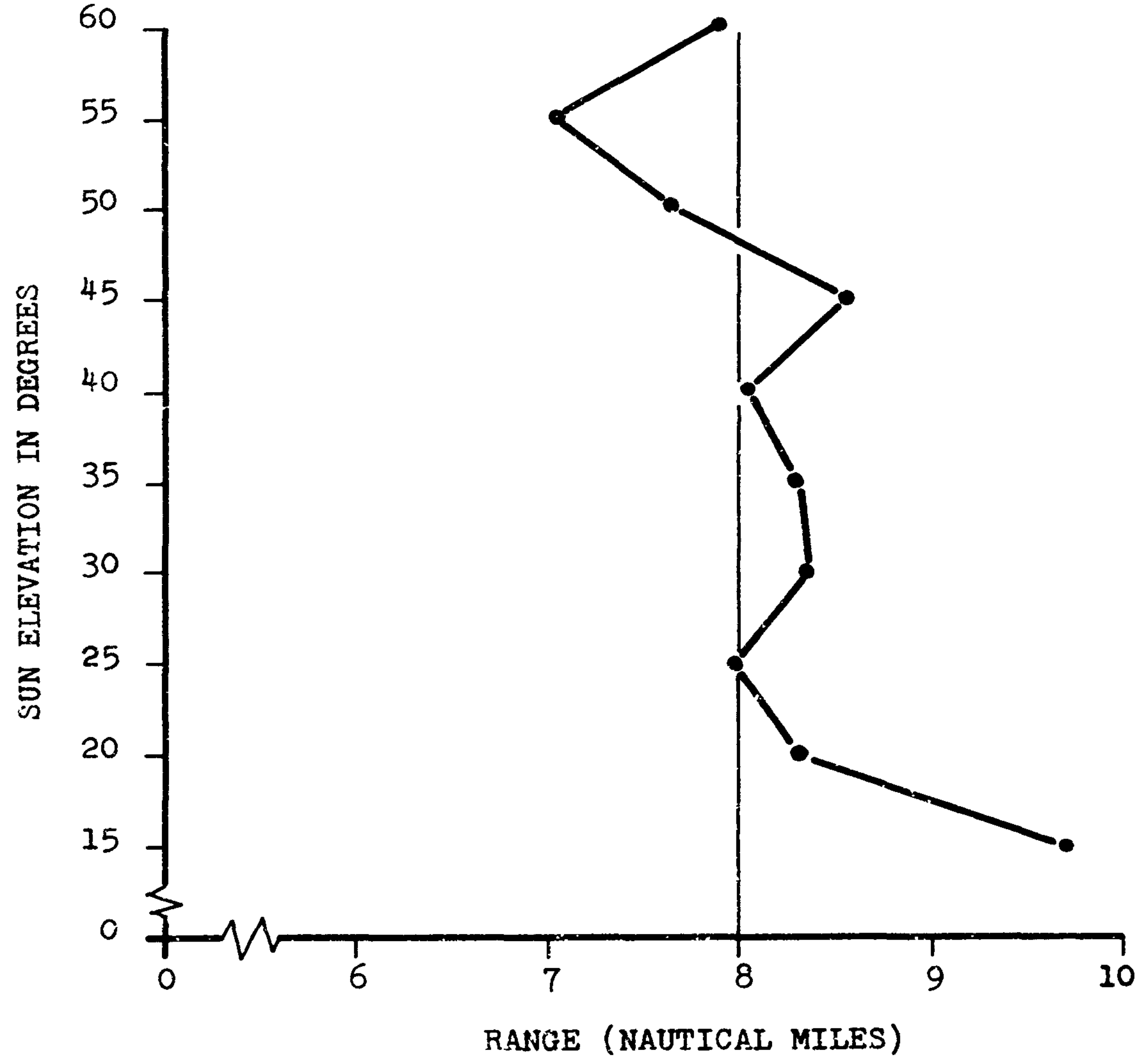

Fig. 12. Average threshold range as a function of sun elevation.

Visual ranges of aircraft were analyzed by time of day observed, so as to take account of certain factors which might otherwise not be amenable to analysis. These include such things as brightness, color of the light, and shadow effects. All observations were taken between 1000 and 1700 hours. Average visual ranges for each hour period varied from 7.84 to 8.05. Hence, it would seem that little variation of visual threshold range occurs during "broad daylight" hours (between 1000 and 1700 hours).

Situational Effects

Any particular sighting of an aircraft has certain features about it that are peculiar to that sighting and are independent of natural phenomena. These we have called situational effects; they include brightness contrast, observer differences, relation of the sun to the aircraft and the observer, and whether the visual threshold has been a detection or a matter of loss after tracking.

The effects of some gross measures of brightness contrast at the moment of detecting or losing the aircraft are shown in Fig. 13. Specular reflection is the bright flash which one gets from reflecting sunlight from a polished surface. These reflections are rather unpredictable, since they depend upon the angle of the sun to the possible reflecting surfaces on the aircraft and to the observer. However, when available, they enable further threshold ranges than any other type of brightness contrast. Certainly for

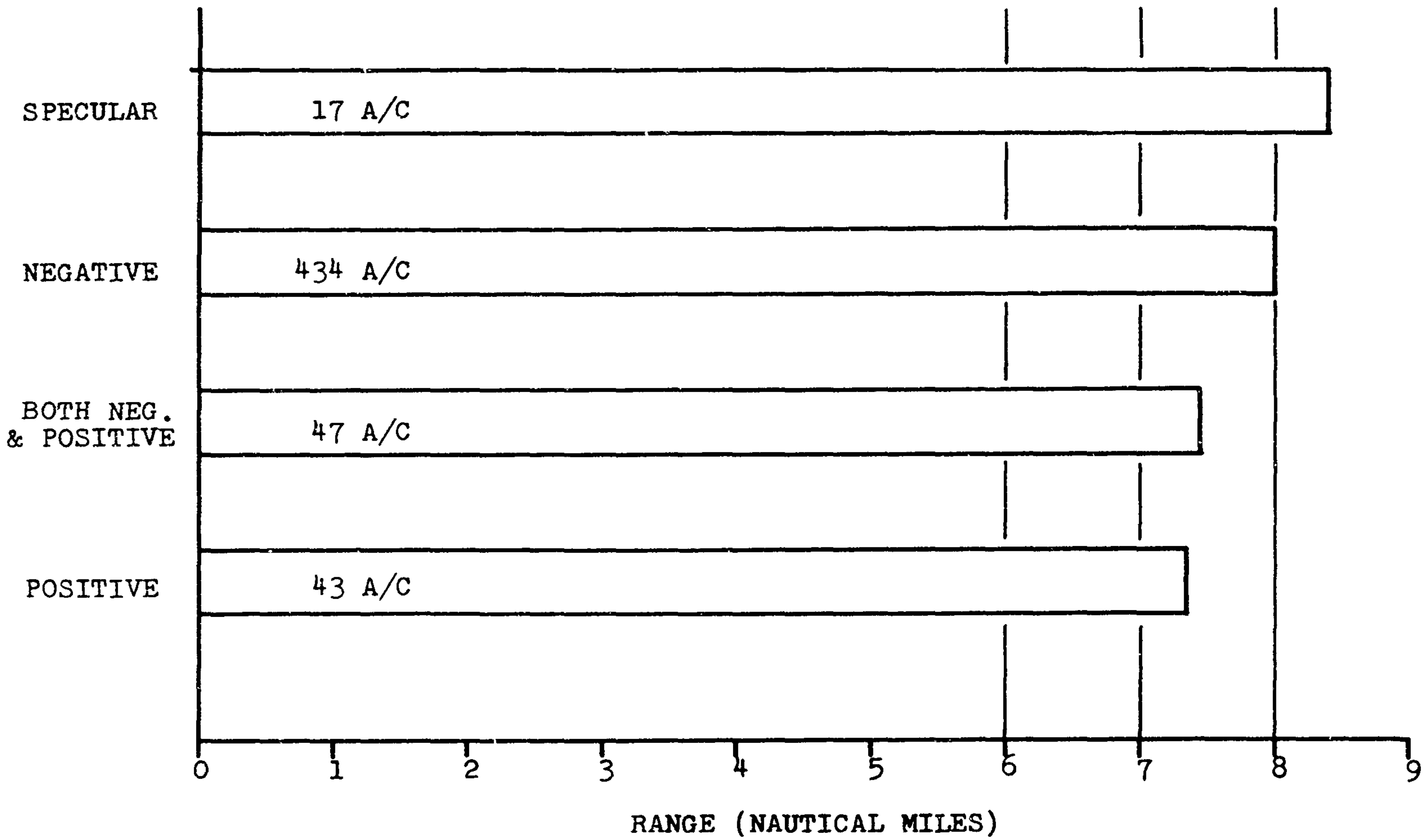

Fig. 13. Average threshold range as a function of brightness contrast.

the greatest number of our observations, contrast at threshold range was negative. The aircraft appeared as a gray or black speck in the sky. Positive contrast was usually evident when aircraft were at closer ranges. This can be seen in the average range for positive contrast, and in those observations where both positive and negative contrast was evident. This latter situation would occur when different sections of the aircraft reflected sunlight differently to a noticeable extent.

Threshold ranges are quite dependent upon whether the aircraft is being tracked until lost, or is being picked up as it is coming toward the observer. In the first instance, the image starts above threshold and is followed until it can no longer be seen; in the second, the image "starts" below threshold and is awaited until it appears.*

The average threshold distance for "appearing" aircraft was 7.4 miles, as opposed to a distance of 8.5 miles for "disappearing" aircraft (those tracked until lost).

Observer differences in threshold ranges were rather great. Four of the observers averaged between 8 and 9 miles

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* In classical psychophysics, the measurement of absolute threshold incorporates both "appearance" and "disappearance" of stimuli: it is on this basis that tracking and detection were included in our observations of aircraft. Threshold as used in this study indicates the mean or arithmetic average distance at which the aircraft were seen both arriving and departing.

threshold range, while two others averaged less than 7 miles. The difference between the best observer's average threshold range and the poorest observer's range was 3-1/2 miles.

The section on paint effects indicated that "sidelighting" was most helpful to threshold ranges. In those situations where the sun was 90° to the line of sight, threshold ranges were greatest. In that discussion, aircraft aspect had not been considered. To investigate the combined effects of aspect relative to sun position, all observations were classified into five categories (types) of possible situations. These situations are diagrammed in Fig. 14, which also presents the average threshold range for each situation.

In this analysis, "sidelighting" loses the advantage it held when aspect was not considered. The greatest threshold range occurred with the observer looking in the direction of the sun at the side view of the aircraft. Next greatest range occurred when the sun was behind an observer who was looking at the aircraft head-on or tail-on. Broadside views with the sun behind the observer gave the next greatest range. The sidelighted situations were next, while the least favorable situation was that in which the observer was looking in the direction of the sun, viewing the aircraft head-on or tail-on.

The ranking for these viewing situations does not agree

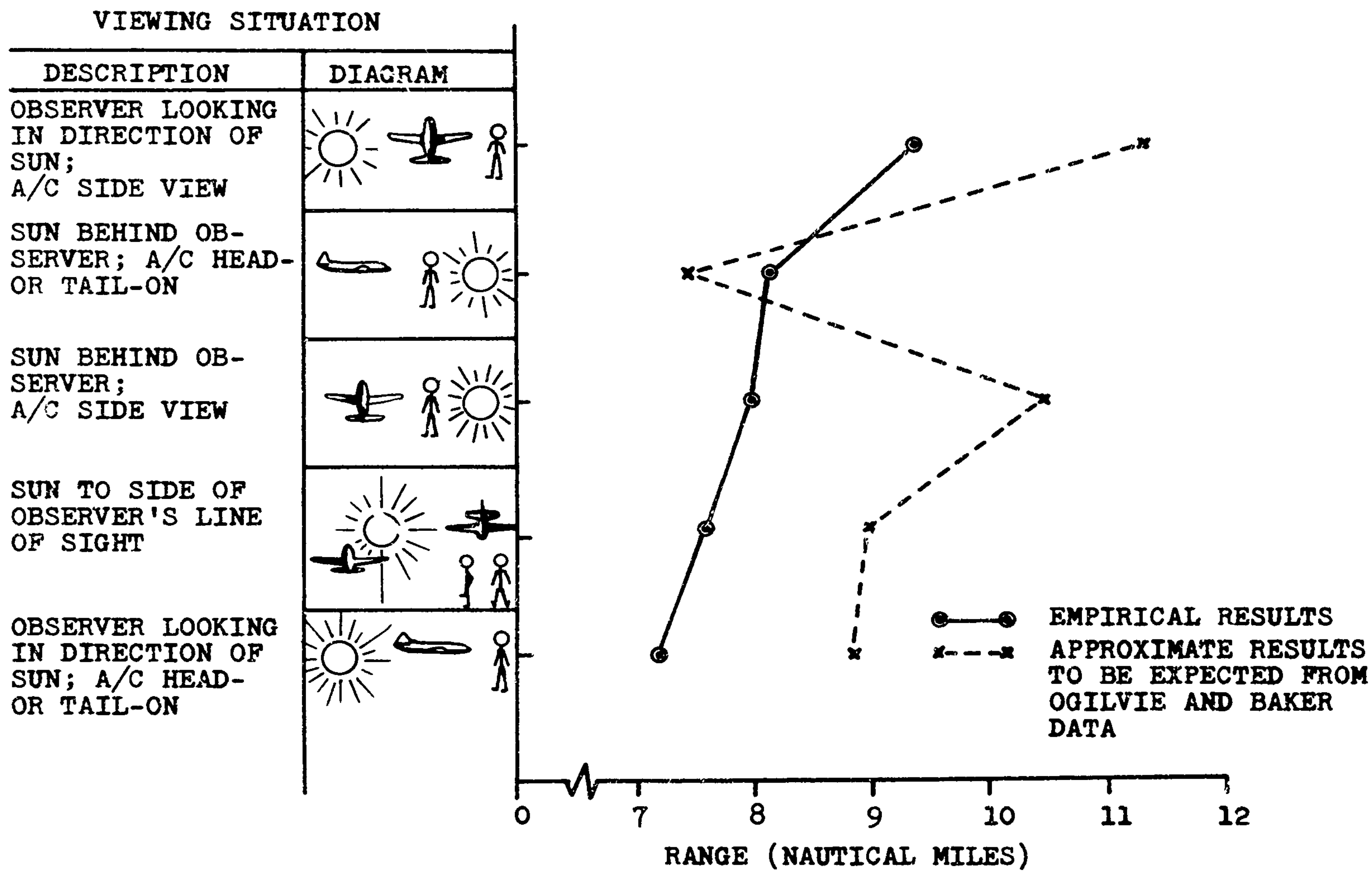

Fig. 14. Average threshold range as a function of aspect and relative position of the sun.

perfectly with the ranking of theoretical ranges for aluminum targets as proposed by Ogilvie and Baker (1954); they are, however, certainly in line with them. The major disagreement is in the situation when the sun is to the rear of the observer with the aircraft viewed head-on. This situation is ranked last in the Ogilvie and Baker data, but holds second place in these field observation rankings.

For purposes of comparison, an approximation of the results to be expected from the Ogilvie and Baker model is presented in Fig. 14. The important points to note are the rank of each of the viewing situations and the slope of the line joining the points. Absolute range values are unimportant in this comparison, since such values are admittedly approximations in the case of the theoretical data*.

Aircraft Size

The size of the image is an important determinant of threshold range. Two important features of the size of the image are the size of the aircraft itself, and the aspect in which it is viewed.

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* This comparison, between the ranges proposed by Ogilvie and Baker and the empirical ranges found in this report, should not be construed as evidence against the theoretical model, since not all of the assumptions of the theoretical model were met.

For purposes of analysis the various types and models of aircraft observed during this study were classified into large, medium, and small categories. Because of the impracticability of determining visual cross-section area equivalents for all the various aspects, or viewing angles, of the many types of aircraft observed, it was decided to classify the aircraft according to their combined wingspans and fuselage lengths. Cut-off values of wingspan plus length for each size category were arbitrarily selected, as indicated in Table 1, which lists a majority of the types of aircraft observed.

Aspects were grouped according to their relative size, as if the aircraft is seen in silhouette. Thus the head-on and tail-on aspects were grouped together, as were the 3 and 9 o'clock aspects. In silhouette, the 1 and 5 o'clock aspects appear the same (except for direction) as the 7 and 11 o'clock aspects. Hence, these four aspects were grouped together. By the same reasoning, the 2, 4, 8,and 10 o'clock aspects were grouped.

It was expected that threshold range would be related both to aircraft size and to aircraft aspect. The larger aircraft would be seen further, as would the aspects presenting the greater amount of viewing area. Table 2 summarizes the results of these two analyses. For size, the relationship holds as expected--the larger the aircraft, the further it is seen. The relationship for aspect is not

Table 1

Method of Categorizing Aircraft Sizes

Type	Wingspan (W)	Length (L)	Combined (W + L)
Large Aircraft			
Lockheed Constellation	123/150	114	237/264
Douglas DC-7	118/128	108/112	226/240
Douglas DC-6	118	101/106	219/224
Douglas DC-4	118	94	212
Lockheed Electra	99	104	203
Medium Aircraft			
Fairchild C-123	110	76	186
Convair (2 eng.)	105	79	184
Vickers Viscount	94	82/85	176/179
Fairchild F-27	95	77	172
Martin (2 eng.)	93	75	168
Douglas DC-3	95	64	159
Grumman Gulfstream	78	64	132
Grumman S-2F	70	42	112
Small Aircraft			
Twin-engine types	36/49	25/35	61/84
Single-engine types	29/33	21/25	50/58

Table 2

Average Threshold Range as a Function of Aircraft Size and Aspect

Size	Aspect (o'clock views)				Average Across Aspects
	6,12	1,5 7,11	2,4 8,10	3,9	
Large	8.1	9.4	8.6	8.9	8.5
Medium	7.5	9.2	8.4	10.0	8.0
Small	6.1	6.1	5.2	5.8	6.0
Average Across Size	7.6	8.8	8.3	8.4	

completely as expected. Three of the aspect groupings are ordered in the expected direction on threshold range. The head-on, the 2, 4, 8, and 10 o'clock, and the broadside aspects do increase as would be predicted (disregarding some minor sampling variations for the small aircraft). The 1, 5, 7, 11 aspects yield the greatest ranges, for some unknown reason. Sample sizes are adequate, and it is unlikely the out-of-line value represents merely chance variation.

In order to get some estimate of the contribution of the size of the image to the threshold range (as opposed to some of the other variables previously discussed) a rough computation of aircraft viewing area was devised. What was wanted was some rough method of approximating the fact that a large aircraft seen head-on may present a smaller viewing area than a medium or small aircraft seen broadside. The particular assignment of values to each size-aspect grouping is spelled out in Table 3. The correlation between viewing areas as determined above and threshold ranges was 0.28, which means that viewing area was far from the sole determinant of threshold range.

Color Identification Ranges

The range at which color can be identified is important if color coding of aircraft is to be used as a collision-avoidance technique. Any paint coding of aircraft is directly dependent upon seeing and being able to identify the particular colors used.

Table 3

Assignment of Values to Various

Aircraft Size-Aspect Groupings

Size	Value (S)	Aspects	Value (A)	Viewing Area (S x A)
Large	3	3, 9	4	12
Large	3	2,4,8,10	3	9
Large	3	1,5,7,11	2	6
Large	3	6,12	1	3
Medium	2	3,9	4	8
Medium	2	2,4,8,10	3	6
Medium	2	1,5,7,11	2	4
Medium	2	6,12	1	2
Small	1	3,9	4	4
Small	1	2,4,8,10	3	3
Small	1	1,5,7,11	2	2
Small	1	6,12	1	1

Figure 15 presents the ranges at which several colors were identified or lost. (Colors were identified as aircraft came closer to the observer, and were lost as aircraft went away from the observer's position. Throughout this report these are both referred to as "color identification ranges.") This figure indicates that the only colors having any advantage are the fluorescent ones. Among the non-fluorescent colors, there were no differences in color identification ranges. They average about one mile, as opposed to 2-1/3 miles for fluorescent colors. Figure 16 presents the advantage of fluorescent colors more dramatically; from it can be seen that over 60 per cent of aircraft with fluorescent paint had color identified at two miles or more, while only 12 per cent of the aircraft with non-fluorescent colors had their color identified at these ranges.

There is little difference in color identification threshold of arriving and departing aircraft. On the average, color was tracked for 1.4 miles, and detected at 1.1 miles.

Although these ranges may be disappointingly short, the positive contribution of this finding is that the use of color as a collision-avoidance aid should be aimed at providing information that will be of most value to pilots in short-range situations.

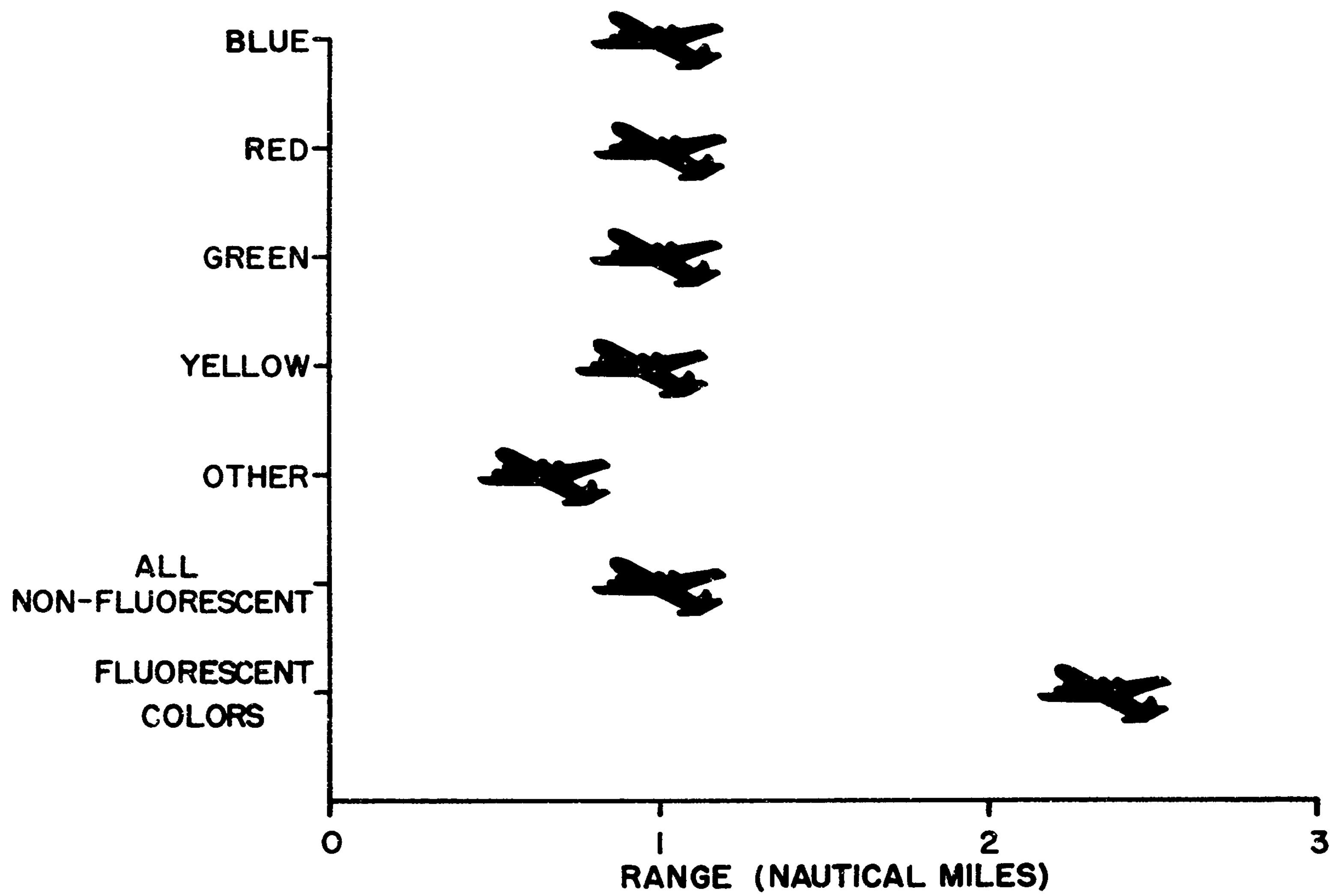

Fig. 15. Average color identification range for various colors.

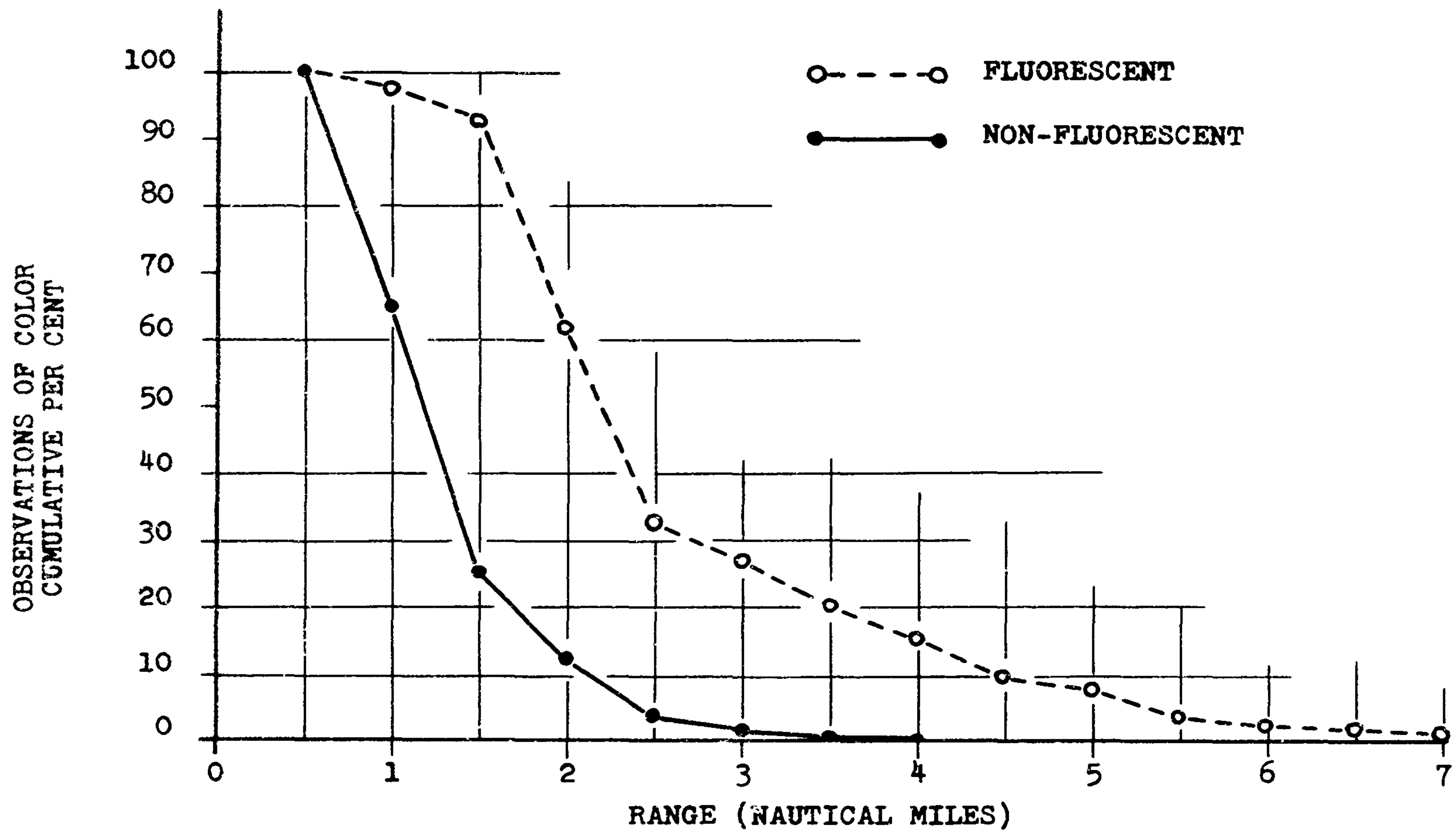

Fig. 16. Cumulative per cent of color seen at each range.

Summary

A total of 541 ground-to-air observations was made under field conditions to establish the threshold ranges for detection of aircraft, and for color identification of the same aircraft. The reader is cautioned to interpret the data within the general limitations of field investigations.

Aircraft threshold ranges were examined to note the possible influence of paints, environmental effects, situational effects, and aircraft characteristics. Paints were found to have no apparent effect on aircraft threshold ranges (detection at maximum range). Ground visibility was found to be related to threshold range, but not perfectly. Threshold ranges were not always limited to the reported visibility range, although, on the average, they were somewhat lower than the ground visibility range. Threshold ranges were greater when cloud backgrounds were present, but no clear correlation could be found between threshold range and the amount of cloud coverage. Slightly greater threshold ranges were found as sun elevation lessened, and time of day had no relation to threshold range.

Specular reflections yielded the greatest threshold ranges, and negative contrast (dark aircraft against light background) yielded intermediate threshold ranges, while

positive contrast (light aircraft against dark background) yielded shortest threshold ranges. Departing aircraft could be tracked to greater ranges than arriving aircraft could be detected. Observer differences may be considerable, even for persons with 20/20 visual acuity. The ranking of threshold ranges for various relative positions of sun, aircraft, and observers was found to follow fairly closely the relative rankings of these situations as predicted by a theoretical model.

Size of aircraft was related to threshold range. The aircraft aspect viewed was also related, but not as completely as expected, when size of image is used for making predictions.

All non-fluorescent colors were identified at an average range of one mile. Fluorescent colors were found to be identified at more than twice that distance.

Reference

Ogilvie, J. C. and Baker, C. H. Charts of air to air visibility of aircraft in the upper atmosphere. Defence Research Medical Laboratories Report No. 87, Toronto, Ontario, Canada, March 1954.